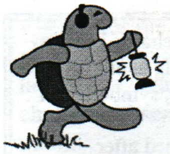


How does a solar cell produce voltage?

> Voltage is measured using a unit called a volt, symbolized **V.** The volt is named after Allesandro Volta (1745-1827) who studied electricity and built an early version of a battery.

The solar cells in the Solar Module are made of a special material that converts light energy into electrical energy. This material is called **photovoltaic***, because the word photovoltaic is a combination of the word *photos* (Greek for light) and the word *voltaic.* This combination of words, *photo* and *voltaic,* tells you that the material produces voltage from light. Voltage is a very important part of the electrical energy that makes different loads work in an electric circuit. So, what is voltage?

Voltage happens because of **electric charge**. Electric charge exists because all physical things are made up of **atoms** of the chemical elements. And all atoms contain two small particles, **electrons** and **protons**, that naturally have electric charge. You can't see electric charge, but it is everywhere around you!

The protons inside an atom have positive (+) electric charge, and the electrons have negative (–) electric charge, as we show in Figure 20. There is a third type of particle in the atom, called a neutron, but neutrons have no electric charge (they are neutral), so we don't need to worry about them. The protons and neutrons stay at the center of the atom, but the electrons move around.

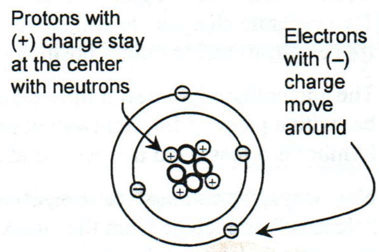


Figure 20: A neutral atom with 4 protons, 4 neutrons and 4 electrons

The solar cells in this Solar Module are made of atoms of three different chemical elements. The main element is silicon, which is found naturally in sand. The two other elements are boron and phosphorus, which are more rare in nature. The boron and phosphorus are added to the silicon in two layers to make a solar cell work the way it does.

If you want to learn more about atoms and the chemical elements, visit Reference 3 on Page 40. The important thing to know (to understand how a solar cell works) is that each chemical element has a different number of protons at the center. As long as an atom has the same number of positive protons and negative electrons, like in Figure 20, the electric charges cancel out and the atom is neutral.

Voltage happens when atoms stop being neutral and electric charges build up. This happens in a solar cell in three steps.

Step 1: Making the solar cell

Figure 21 shows how the atoms in the two layers of a solar cell would look when the cell is first made. The area where the two layers meet is called the p-n junction.

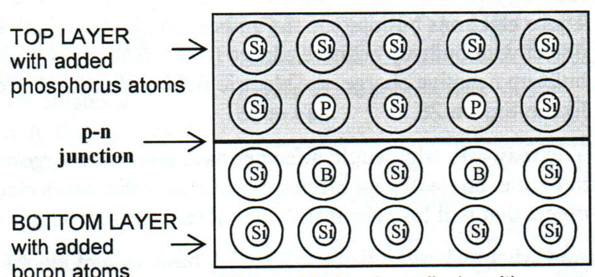


Figure 21: A solar cell when it's first made

Most of the atoms are silicon atoms (labeled **Si**). The element silicon has14 protons and 14 electrons.

There are also some phosphorus atoms in the top layer (labeled **P**), and there are some boron atoms in the bottom layer (labeled **B**). The element phosphorus has 15 protons and 15 electrons. The element boron has 13 protons and 13 electrons.

At first, all these atoms have an equal number of protons and neutrons (they are neutral), so when the solar cell is first made it has no voltage. The voltage gets created because of what happens next.

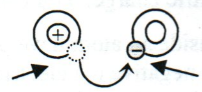
Step 2: The electric field

> Electric charge is measured using a unit called a coulomb, symbolized **C**.
>
> The unit is named after Charles-Augustin de Coulomb (1736-1806) who studied how electric charges affect each other when they are separated.

The voltage of a solar cell happens when electrons get separated from the atoms of the solar cell. Remember that electrons move around away from the center of the atom. So, it's easy for them to leave — it happens all the time in nature!

Sometimes an electron leaves one atom to move to another atom. An atom that has lost an electron has more protons (+) than electrons (–), so it has positive charge. An atom that has gained an electron has more electrons than protons, so it has negative charge. This is shown in Figure 22, where an electron has moved from the atom on the left to the atom on the right.

Figure 22



Sometimes an electron will leave an atom to become a free electron, without getting stuck on another atom. Two separate charges are still created, one negative (the free electron) and the other positive (the positive atom).

The ancient Greeks knew a little bit about electric charge. They found that when they rubbed a piece of amber with a piece of fur, lightweight particles like feathers and straw would be pulled toward the amber. (Amber is a fossilized tree resin that the ancient Greeks used as jewelry).

Nowadays, we call this **static electricity**. The words "electricity" and "electron" both come from the Greek word for amber, *elektra*. Today, scientists understand that static electricity happens because of **electric fields** that surround charged objects. The difference between a positive charge and a negative charge is the direction of the electric field. A positive charge has an electric field pushing out in all directions, as shown by the arrows in Figure 23. A negative charge has an electric field pulling in from all directions, like in Figure 24.

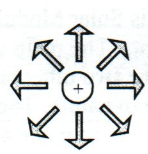


Figure 23

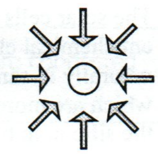


Figure 24

Static electricity happens when amber is rubbed with fur because the energy from rubbing (friction) makes some electrons leave atoms in the fur and move to the amber. Those electrons build up on the amber, giving it a negative charge. When a lightweight object with built-up positive charge (like a feather) is placed near a piece amber with a built-up negative charge, the electric field will make the feather move toward the amber, like in Figure 25.

You may ask, why would a feather have positive charge? When two objects rub together in nature, one will gain electrons while the other loses electrons. A feather is a type of object that will lose electrons when it rubs against other things in nature.

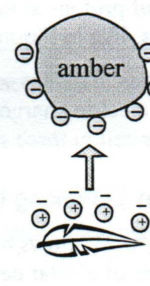


Figure 25

And what makes the feather move? A basic rule of electric charges, that opposite charges attract each other. The electric field pushing out from a positive charge combines with the electric field pulling in from a negative charge, like in Figure 26. The feather is light, so the feather moves toward the amber!

The direction of electric field between two charged object is an important part of how a solar cell works. An object with positive charge moves in the direction of an electric field (the direction of the arrow). An object with negative charge moves against the direction of the electric field (opposite to the direction of the arrow). Learn more about static electricity at Reference 4 on Page 40.

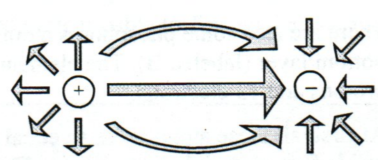


Figure 26

Right after the solar cell is made in Step 1, some electrons on phosphorus atoms in the top layer move to boron atoms in the bottom layer. They leave positive atoms behind, like in Figure 27. When two charges get separated like this, an electric field is created between them.

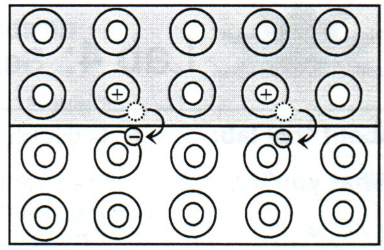


Figure 27: Electrons move from the top layer to the bottom layer

As more electrons leave atoms in the top layer to move to the bottom layer, the electric field ⇩ builds up between the two layers (Figure 28). But as the electric field gets stronger, the direction of the field acts against any more electrons moving to the bottom layer. Remember, electrons want to move opposite to the direction of the arrow—from the bottom layer to the top layer. So, the movement of electrons from the top layer to the bottom layer eventually stops. But, the electric field is still there, because the electrons that have already moved can stay where they are in the bottom layer. And, the positive atoms in the top layer can't move. Now the solar cell is ready for Step 3.

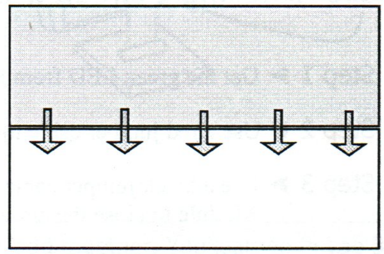


Figure 28: The electric field

Step 3: Light!

In the final step, a photon of light falls on the solar cell. The photon travels into the solar cell material, and strikes an atom (Figure 29). The energy of the photon is absorbed by an electron in the atom, causing the electron to leave the atom to become a free electron. This is called the **photoelectric effect**!

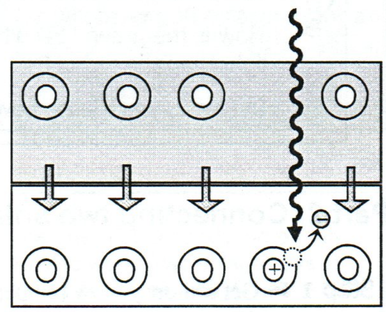


Figure 29: A photon falls on the solar cell

The free electron can move from the bottom layer to the top layer, opposite to the direction of the electric field. But the electric field prevents it from moving from the top layer to the bottom layer. So as electrons are freed in the bottom layer, they move to the top layer and build up there. (Electrons freed by photons in the top layer just stay in the top layer).

When many photons are absorbed, many electrons build up in the top layer of the solar cell. At the same time, positive atoms accumulate in the bottom layer. The separation of free (–) electrons in the top layer from fixed positive (+) atoms in the bottom layer creates a voltage between the two layers. If you connect a wire to the top layer and it becomes a negative terminal! Then, connect a wire to the bottom layer and it becomes a positive terminal! (Figure 30)

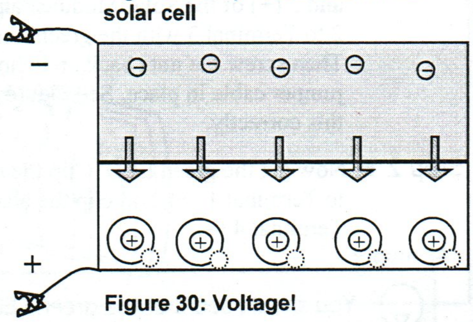


Figure 30: Voltage!

The voltage of a single solar cell is about 0.5 volts. More common voltages that we use in everyday life are between 1.5V (small batteries), 12V (car batteries), and 120V (normal household voltage). The polarity of the voltage tells you which terminal is negative and which is positive. You'll learn more about polarity in Lab 6.

REMEMBER...When light falls on a solar cell, electrons are freed by light. Because of the electric field, freed electrons build up in the top layer. This is what creates voltage between the (+) and (–) terminals.